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PLATE VII. THE METEOR CRATER OF ARIZONA.

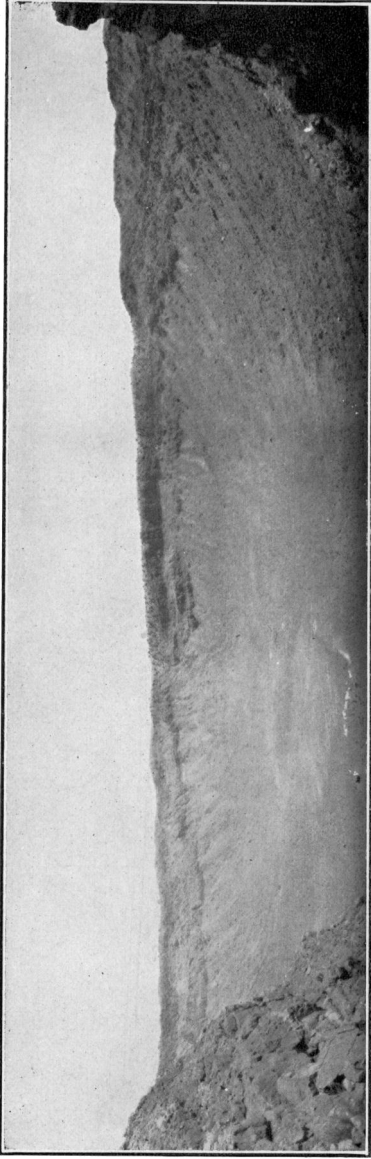


FIG. 1. VIEW LOOKING INTO AND ACROSS THE CRATER

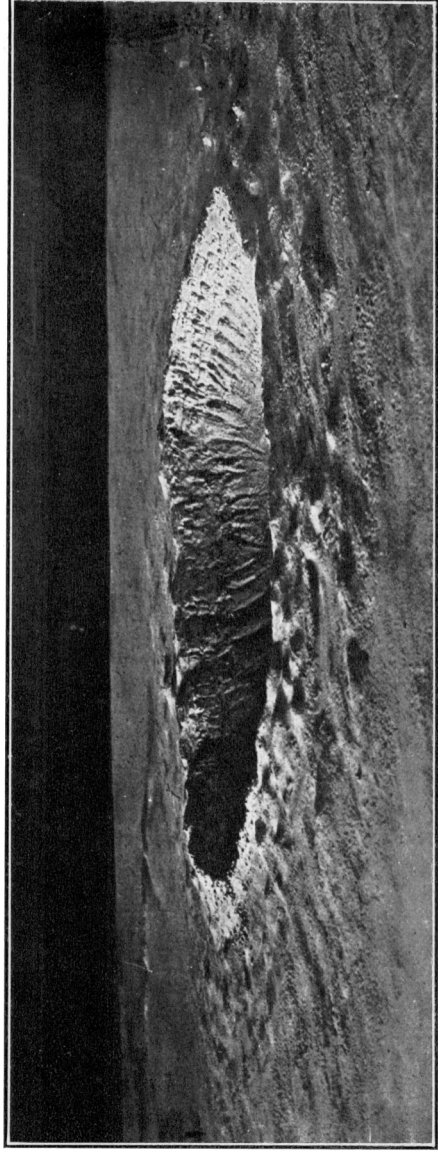


FIG. 2. IDEAL BIRD'S-EYE VIEW OF THE CRATER, FROM A MODEL MADE UNDER THE DIRECTION OF G. K. GILBERT

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A RETROSPECTIVE VIEW OF THE ORIGIN OF METEOR
CRATER, ARIZONA¹

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Recent conversation with Professor W. W. Campbell of the Lick Observatory on Mt. Hamilton, California, relative to the origin of the so-called Meteor Crater in Arizona, together with his paper in the *Publications of the Astronomical Society of the Pacific*², for April last, have led the present writer to review his own work on the subject³ and to present again, in brief, the conclusions there reached, incidentally discussing what further evidence, one way or the other, may have come to his attention, together with reasons for any changes of view, should such there be. In so doing, it will be necessary to assume that the reader has seen the original paper as the subject is too large to be covered thoroly here. It must answer to state that the crater occurs in a region constituting an elevated and nearly level sandy plain, the floor of which is composed, in the main, of a buff colored arenaceous limestone, known as the Aubrey (Carboniferous) limestone, capped here and there by low flat-topped mesas of red sandstone and underlaid by a gray or faintly buff highly siliceous sandstone, also of Carboniferous age, and this in its turn by a yellow sandstone merging into red. The crater is some 4000 feet in diameter, and 600 feet in depth with a rim rising at its highest point 160 feet above the plain, this rim being composed of the lime- and sandstone beds mentioned, tilted at various degrees with the horizon and dipping away in all directions from a common center. Scattered over the surface in the immediate vicinity are enormous blocks of limestone, which have plainly been thrown out from the crater, and a great amount of disintegrated and finely pulverized sandstone from the underlying bed. The origi-

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²Notes on the Problem of the Origin of the Lunar Craters, pp. 126-138.

³The Meteor Crater of Canon Diablo, Arizona, Its History, Origin and Associated Meteoric Irons, *Smithsonian Miscellaneous Collections*, Quarterly issue, Vol. 50, Pt. 4, 1908.

nal depth of the crater cannot be told as it has become filled to its present level by material fallen from the inner walls, sands from the desert, and to a slight extent by beds of diatomaceous earth which must have originated in the temporary lake which at one time occupied the bottom (see Plate VII).

Two possible origins for this crater have been suggested. First, that it is due to explosive volcanic action; and second, to the impact of a giant meteor. Detailed investigations have been made, first by Mr. G. K. Gilbert; secondly by Messrs. Barringer and Tilghman and third, by the present writer. The conclusion reached by the last mentioned, with which alone this paper has to do, was rather in favor of an origin by impact. The facts mentioned below form the chief bases of this conclusion:

(1) Aside from the fact that there is here a crater, there are no evidences suggestive of volcanic action, no lava, and with one exception to be mentioned later, no ejectamenta that can be considered of a volcanic or solfataric character and that could not have been supplied by winds from distant volcanic centers.

(2) The rocks involved are wholly of a sedimentary nature.

(3) They are turned up at various angles in a manner which is highly suggestive of the displacement of material under the force of impact from without, altho it is evident that this condition might also be the result of explosive action from beneath.

(4) The ejected material on the slopes about the crater suggest that the agency, whatever it may have been, must have been sudden and of tremendous power, some of the ejected blocks weighing probably thousands of tons.

(5) There are no evidences of long continued activity. It would appear that the forces, whatever they may have been, acted suddenly, vigorously and abruptly ceased, altho it is possible that solfataric action might have continued for a considerable length of time in the one-time bottom of the crater, which is now hopelessly obscured.

(6) Considerable weight was attached to the presence both within and without the crater of thousands of tons of finely disintegrated material which plainly resulted from the shattering of the quartz grains in the sandstone, the particles being in a condition such as would result from a sudden explosion which produced not merely disintegration but the shattering of the individual grains themselves.

(7) In addition to the above, there were found both in borings and scattered about on the plain, masses of siliceous material in a highly altered condition which it was thought could be traced back to metamorphic influences such as would be induced by the enormous heat and pressure incidental to the downward plunge of a heavy meteoric body.

(8) Borings, made in extreme cases to the depth of 1100 feet below the present crater bottom, while showing no solid meteoric masses, did bring up from certain levels (450-650 ft.), pulverulent material which not merely reacted for nickel but which yielded at times small metallic particles which tests showed could not have come from the drill and which in their turn, yielded reactions for phosphorus, nickel and iron, indicative of schreibersite, a constituent of nearly all meteoric irons.

(9) Lastly, from the extreme depths to which the borings extended there were brought up cores of the deeper lying red and yellow sandstone, the granules of which were still intact with no signs of physical or chemical alteration, indicating that the sources active in the formation of the crater were limited to the overlying limestone and sandstone, and did not originate in the depths below.

In reviewing the subject, the writer has once more gone over his notes and materials and made additional chemical tests and finds no reason for changing the conclusions first reached which are based on the character of the evidence, as he understands it, quite regardless of any similarity between existing phenomena and the problematic craters of the Moon. The overlying limestone is wholly unaltered. The five hundred or more feet of sandstone in which the main body of the crater lies, as previously described, are shattered, and in reviewing the subject, a feature has come to light which the writer finds, to his astonishment, is not mentioned in the previous paper but which was considered at the time of the investigation and overlooked in the compilation of the final report. This detail of structure which is considered of importance is as follows:

The rocks around the rim are turned up at various angles from their original horizontal position as already mentioned. In one case particularly on the eastern rim, the underlying sandstone strata are even inverted (see Fig. 1). More than that, the sandstone beds so far as they can be seen—unfortunately they are greatly obscured by fallen and indrifting material—are shattered almost beyond recognition. As already stated, there are no indications whatever of in-

truded matter. In fact, it is certain there is none. The question at once arises, what, then, holds the beds in their present uplifted condition? Were this due to explosive action from beneath, they must, so soon as the forces ceased action, have fallen back into a horizontal position simply thru the action of gravity. This is precisely what has happened with explosive volcanic craters in other parts of Arizona and New Mexico with which this has been compared by those not sufficiently acquainted with details.⁴ In the

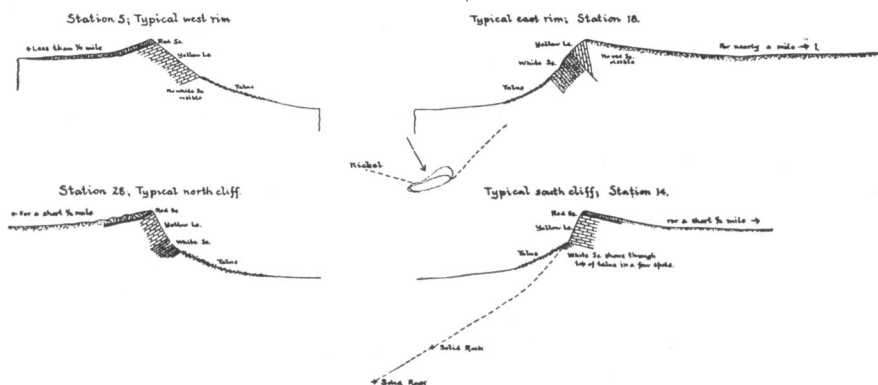


FIG. 1

writer's opinion this condition of the beds can be accounted for only on the supposition that the sandstone has been driven back horizontally and the bed locally thickened by the impact of some large body which displaced the material once occupying the crater site throwing a portion out upon the surface and driving the remainder wedgelike back under the limestone. This, as stated, was noted at the time of the first observations but probably its full significance was not impressed upon me until attention was called to it by certain criticisms made by those advocating a volcanic hypothesis.

As stated above, the writer has gone over once more his sections and repeated certain chemical tests. While no solid masses of meteoric material were found within the crater, there was brought up with the greatest regularity from the drill holes and from depths varying from 450-650 feet, disintegrated material reacting for constituents characteristic of meteorites. It is possible, of course, that a portion of this material might have been brought in by winds from

⁴The criticisms of J. F. Niermeyer (see accompanying bibliography) show an almost hopeless inability on his part to realize the true condition of affairs.

the weathering of the blocks of meteoric iron which have been scattered in such quantity over the region northwest of the crater. This, however, is not deemed at all probable owing to the apparent regularity in depth below the surface of the stratum from which this material is derived.

The writer's previously expressed view regarding the origin of the crater remains, then, unaltered and is to the effect that the crater form is due to impact from without. Whether the meteoric material found in the vicinity today is merely a coincidence or a part of the material instrumental in the production of the crater, is really immaterial, the present tilted position of the beds in themselves being regarded as conclusive evidence of an origin by some force which pressed downward crowding the friable sandstone back beneath the limestone as already described.

There is, however, one item of negative evidence, or at least of evidence of a doubtful character and of a considerable degree of importance which should be mentioned in this connection. I refer to the masses of what has been called "silica pumice" and "ghost sandstone" which have been found on the surface of the plain in the immediate vicinity and large masses of which constitute the immediate floor of the crater about the cabins on the slope. This material has been traced back to the Aubrey sandstone from which it is felt it was derived beyond question. But if so, what was the source of the heat sufficient to convert it into its present condition? It does not seem possible that it is due to solfataric agencies. If it were the heat of impact of a meteoric body, how does it happen that the material is now scattered over the surrounding surface? In the original paper, it was suggested that this might be explained as simply in the nature of a flareback. That the sandstone at the depth below the surface at which this action took place contained moisture, is, of course, probable. The heat incidental to impact, if sufficient to fuse the sandstone, must have converted this moisture instantly into steam with a tremendous explosive energy and this in its turn would result in throwing the altered material back upon the surface and, possibly, with it whatever meteoric material may have escaped volatilization by the tremendous heat developed. This is the only explanation that the writer could give at the time or which seems worthy of consideration today, tho he does not consider it quite satisfactory.

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